

APPENDIX B SEISMIC HAZARD ESTIMATES

This appendix contains additional discussion of the U.S. Geological Survey (USGS) seismic hazard model used to develop the hazard estimates used in this Safety/Risk Assessment, the site-specific adjustments to the rock hazard estimates for sites that could not be considered to be founded on hard rock, and a summary of results. A brief discussion and summary of the Lawrence Livermore National Laboratory (LLNL) and Electric Power Research Institute (EPRI) results that were available at the time of the Individual Plant Examination for External Events (IPEEE) assessments are also included.

B.1 USGS Hazard Model and Site Amplification

The hazard results used this evaluation were produced with the publicly available source codes and input files obtained from the USGS National Hazard Mapping group. These codes and example inputs can be obtained from the USGS Web site (`hazgridXnga2.f` and `hazFXnga7.f` and associated batch scripts). These codes and inputs form the basis of the 2008 National Seismic Hazard maps and were developed in a UNIX operating environment. NRC staff recompiled the codes (with minor modifications) to operate in an MS-Windows environment. The codes were successfully benchmarked against publicly available USGS hazard results assuming a near-surface shear wave velocity of 760 meters/second at several sites.

The USGS model recognizes that significant epistemic uncertainty exists in numerous elements of the model and incorporates those uncertainties using a logic tree approach. Simple batch scripts are used to produce results for each branch through the logic tree and to combine intermediate results. Figures B.1 shows the logic structure of the seismicity-derived hazard component in the central and eastern United States (CEUS), and Figures B.2 and B.3 show the logic trees for the New Madrid, and Charleston source zone components of hazard, respectively. The maximum magnitude (M_{MAX}) that is assigned in the model to compute the seismicity-based hazard contribution is dependent on location within the CEUS. Figure B.4 shows a map with the distribution of M_{MAX} by region. Extensive discussion and documentation on the approach to estimating seismic hazards in the CEUS is contained in the publicly available USGS literature (Frankel and others, 1996; 2002; and Petersen and others, 2008).

Current NRC guidance for the estimation of design ground motions for new plants (Regulatory Guide 1.208) allows for a period and amplitude-dependent reduction in event frequency to represent the observation that some fraction of earthquake ground motions of a given amplitude fall below the threshold of damage for most engineered structures. One measure of this threshold is the cumulative absolute velocity (or CAV) value. The present assessment has not included the CAV-threshold effect for two reasons. First, some portion of the uncertainty included in the estimate of fragility may be due to a mixed population of CAV values (i.e., some above the threshold, some below). No obvious documentation exists that illustrates only records that exceed a specific CAV threshold were used to estimate fragilities. In the interest of avoiding a double-counting of this effect, no CAV-filtering has been applied. Second, the existing USGS hazard code does not include a CAV-threshold effect. To add this feature would require significant software modification. In the interest of moving forward in the safety/risk assessment phase of this project, no CAV modifications were added to the USGS hazard code.

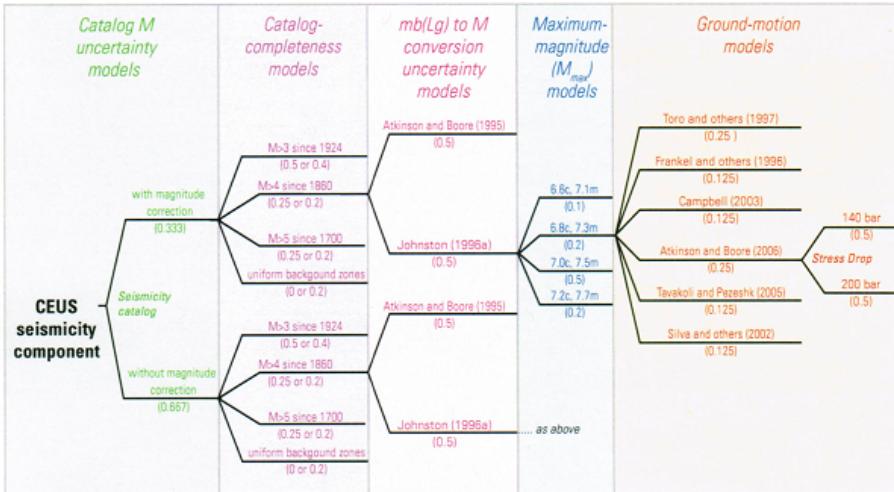


Figure 2. Logic tree for seismicity-derived hazard component in the Central and Eastern United States (CEUS). Each maximum-magnitude branch includes craton (c) and margin (m) estimates. Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. We treat aleatory variability in ground motion in the hazard code.

Figure B.1. Logic Tree for Seismicity-Derived Hazard Component Used in the USGS Model for the CEUS (from USGS Open-File Rep. 2008-1128).

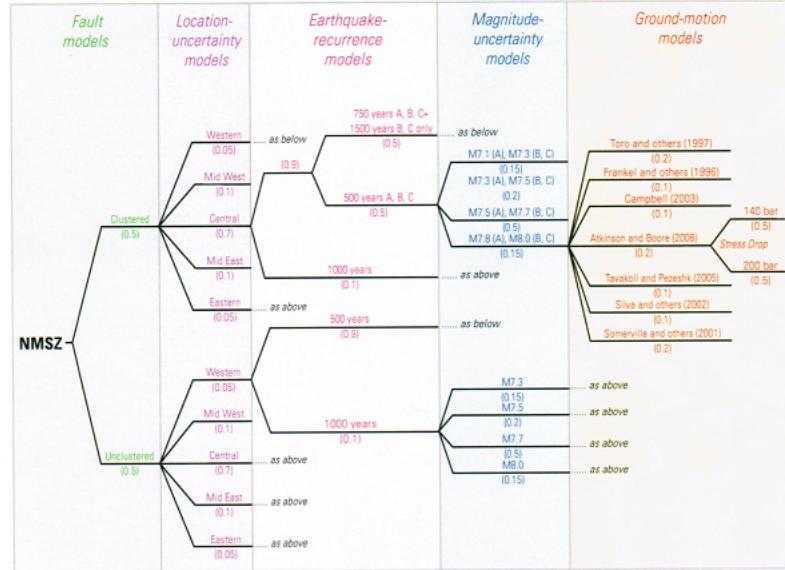


Figure 6. Logic tree for the New Madrid seismic zone (NMSZ). Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. A, B, and C refer to the northern, central, and southern segments shown in figure 5. Location and magnitude branches may include aleatory variability and epistemic uncertainty; we have not treated these separately. We treat aleatory variability in ground motion in the hazard code.

Figure B.2. Logic Tree for New Madrid Seismic Zone Used in USGS Seismic Hazard Model (from U.S.G.S Open-File Rep. 2008-1128).

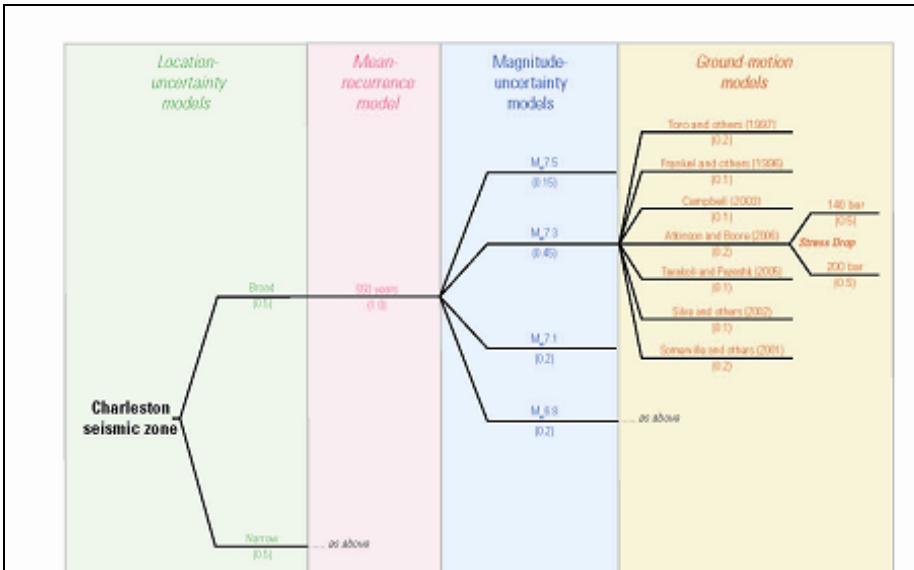


Figure 8. Logic tree for the Charleston seismic zone. Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. Additional aleatory variability may be associated with location and magnitude models. We treat aleatory variability in ground motion in the hazard code.

Figure B.3. Logic Tree for Charleston Seismic Zone Used in USGS Seismic Hazard Model (from U.S.G.S Open-File Rep. 2008-1128).

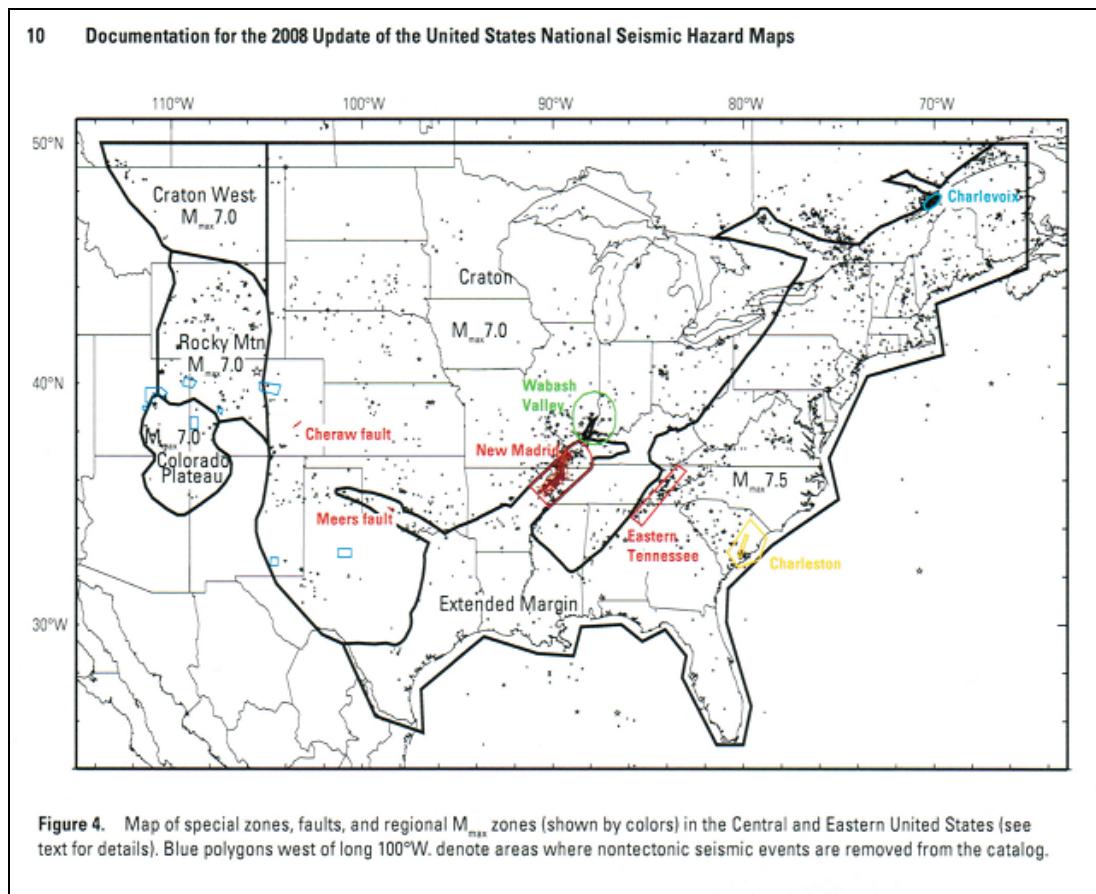
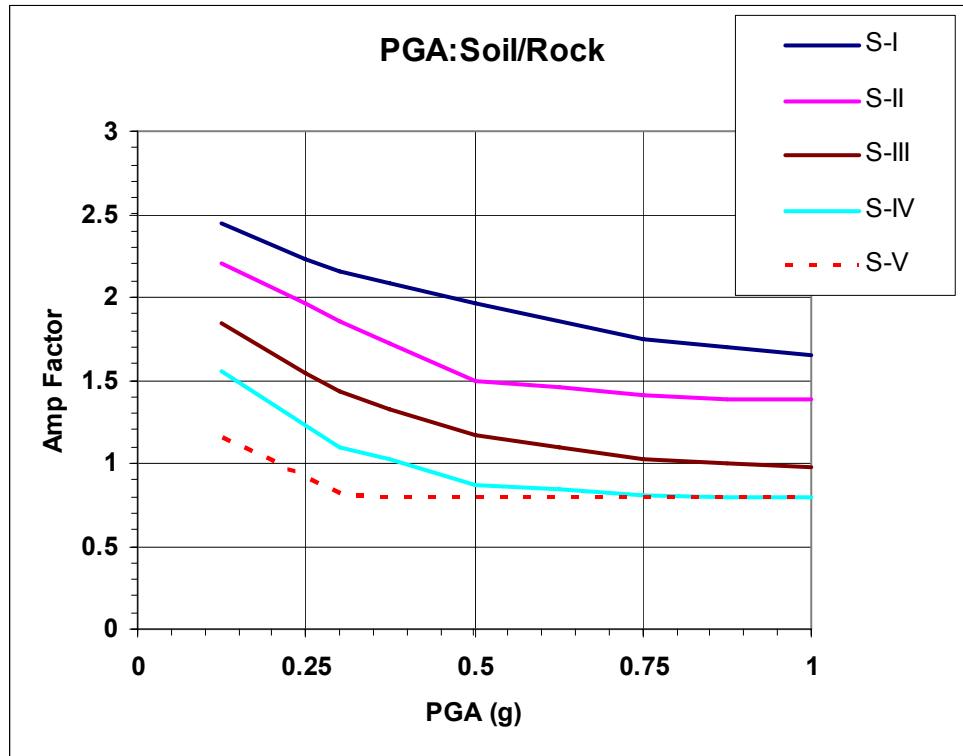


Figure B.4. Map of CEUS illustrating regions with different M_{MAX} assigned (from USGS Open-File Rep. 2008-1128).

To produce site-specific results appropriate for this assessment, the hazard codes were run (consistent with the logic trees outlined in the 2008 hazard documentation) for the latitude and longitude of each nuclear power plant (NPP) assuming a near-surface shear wave velocity of 2,500 meters/second. This velocity is consistent with “hard-rock” for all the attenuation relationships used in the calculations. For those NPPs with soil site conditions, site conditions were assigned to be consistent with the definitions in EPRI-NP-6935 (1989). These site conditions are denoted as S1, S2, S3, S4, S5 or SS (site-specific). The period and amplitude dependent site amplification factors in EPRI-NP-6935 (1989) do not extend to high enough amplitude to cover the complete range of contribution to seismic core-damage frequency (SCDF). Hence, it was necessary to extrapolate the amplification factors. Some judgment was required for this step. The existing EPRI site amplification curves do not allow the amplification to fall below 0.8. To be consistent, the extrapolated curves were not allowed to fall below 0.8. For thin soil site types where the site amplifications were increasing, some curvature or

truncation was introduced in the curves to prevent very high levels of amplification from occurring at high amplitude because nonlinear effects will be manifested in even thin soils at high amplitude levels. Figure B.5 shows example soil amplification factors.



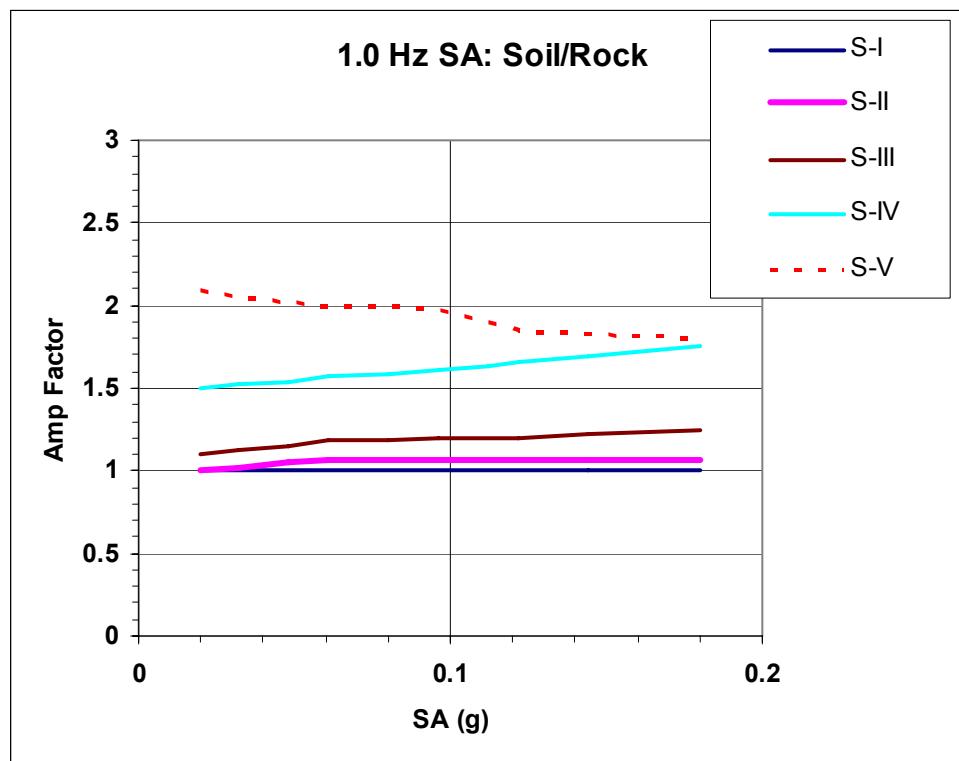


Figure B-5. Generic Site Amplification Factors Used for Soil Sites, Factors for PGA (top) and 1-sec SA (bottom). The site amplification factors are from EPRI-NP-6935 (1989).

Table B.1 summarizes the generic site characteristics assumed in the EPRI-NP-6935 (1989) analyses. Table B.2 summarizes the site types, IPEEE evaluation method, spectral shape, safe shutdown earthquake (SSE_{PGA}), and high confidence of a low probability of failure ($HCLPF_{PGA}$) values for each NPP site.

Table B.1. Site Categories and Depth Ranges
[from EPRI NP-6395-D]

Category	Average Depth		Depth Range		Soil Avg Vs f/s	Soil Avg Vs m/s
	ft	m	ft	m		
I	20	6	10.0-30	3.0-9	1125	343
II	50	15	30-80	9.0-24	1325	404
III	120	37	80-180	24-55	1600	488
IV	250	76	180-400	55-122	1900	579
V	500	152	>400	>122	2234	681

Table B.2. Summary of Site Types, Evaluation Methods, HCLPF, and SSE Values

Site	Site Type	IPEEE Evaluation Approach	RLE Spectral Shape	HCLPF_{PGA} (g's)	SSE_{PGA} (g's)
Arkansas 1	Rock	Full-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Arkansas 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Beaver Valley 1	Soil III	Seismic PRA	EPRI-UHS	0.2	0.12
Beaver Valley 2	Soil III	Seismic PRA	EPRI-UHS	0.24	0.12
Braidwood 1&2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Browns Ferry 1	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Browns Ferry 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.26	0.2
Brunswick 1&2	Soil III	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.16
Byron 1&2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Callaway	Rock	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.2
Calvert Cliffs 1&2	Soil V	Seismic PRA	LLNL-UHS	0.3	0.15
Catawba 1&2	Rock	Seismic PRA	Sequoiah Spectra	0.23	0.15
Clinton	Soil IV	Focused-Scope EPRI-SMA	Multiple-Soil	0.3	0.25
Comanche Peak 1&2	Rock	Reduced-Scope EPRI-SMA	Plant-SSE	0.12	0.12
Cooper	Soil III fsar	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.2
Crystal River	Rock	Reduced-Scope EPRI-SMA	Housner-Soil	0.1	0.1
D.C. Cook 1&2	Soil II fsar	Seismic PRA	EPRI-UHS	0.26	0.2
Davis Besse	Rock	Reduced-Scope EPRI-SMA	Rock-NUREG-0098	0.26	0.15
Dresden 2&3	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.2	0.2
Duane Arnold	Soil II fsar	Reduced-Scope EPRI-SMA	SSE-Rock/Soil	0.12	0.12
Farley 1&2	Rock	Focused-Scope EPRI-SMA	Plant-SSE	0.1	0.1
Fermi 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.15
Fitzpatrick	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.22	0.15
Fort Calhoun 1	Soil III fsar	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.25	0.17
Ginna	Rock	Focused-Scope EPRI-SMA	R.G. 1.60 Rock	0.2	0.2
Grand Gulf	Soil V	Reduced-Scope EPRI-SMA	SSE Soil	0.15	0.15
Hatch 1&2	Soil V	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.15
Hope Creek	Soil V	Seismic PRA	EPRI-UHS	0.3	0.2
Indian Point 2	Rock	Seismic PRA	EPRI-UHS	0.3	0.15
Indian Point 3	Rock	Seismic PRA	LLNL-UHS	0.15	0.15
Kewaunee	Soil (SS)	Seismic PRA	LLNL-UHS	0.23	0.12
LaSalle 1&2	Soil III	Simplified Seismic PRA	Unknown	0.3	0.2
Limerick	Rock	Reduced-Scope EPRI-SMA	Plant-SSE	0.15	0.15
McGuire 1&2	Rock	Seismic PRA	NUREG-0098	0.26	0.15
Millstone 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.25	0.17
Millstone 3	Rock	Seismic PRA	Site Specific	0.3	0.17

Monticello	Soil II	Reduced-Scope EPRI-SMA	Plant-SSE	0.12	0.12
Nine Mile Point 1	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.27	0.11
Nine Mile Point 2	Rock	SPRA &Focused EPRI-SMA	Rock-NUREG-0098	0.23	0.15
North Anna 1&2	Rock	Focused-Scope EPRI-SMA	Rock/Soil-NUREG-0098	0.16	0.12
Oconee 1,2&3	Rock	Seismic PRA	EPRI-UHS	0.29	0.1
Oyster Creek	Soil V	Seismic PRA	EPRI-UHS	0.16	0.17
Palisades	Soil III fsar	Seismic PRA	LLNL-UHS	0.22	0.2
Peach Bottom 2&3	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.2	0.12
Perry	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.15
Pilgrim 1	Soil III	Seismic PRA	LLNL-UHS	0.25	0.15
Point Beach 1&2	Soil II	Seismic PRA	LLNL-UHS	0.16	0.12
Prairie Island 1&2	Soil II	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.28	0.12
Quad Cities 1&2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.09	0.24
River Bend	Soil (SS)	Reduced-Scope EPRI-SMA	SSE-Soil	0.1	0.1
Robinson (HR)	Soil V	Full-Scope EPRI-SMA	Soil-NUREG-0098	0.28	0.2
Saint Lucie	Soil V fsar	Site-Specific	Plant-SSE	0.1	0.1
Salem 1&2	Soil V	Seismic PRA	EPRI-UHS	0.3	0.2
Seabrook	Rock	Seismic PRA	R.G. 1.60 Rock	0.27	0.25
Sequoyah 1&2	Rock	Full-Scope EPRI-SMA	NUREG-0098	0.27	0.18
Shearon Harris 1	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.29	0.15
South Texas 1&2	Soil (SS)	Seismic PRA	River Bend Spectra	0.096	0.1
Summer	Rock	Focused-Scope EPRI-SMA	NUREG-0098 Rock/Soil	0.22	0.15
Surry 1&2	Soil V	Seismic PRA	EPRI-UHS	0.16	0.15
Susquehanna 1&2	Rock	Focused-Scope EPRI-SMA	NUREG-0098 Rock/Soil	0.21	0.1
Three Mile Island 1	Rock	Seismic PRA	EPRI-UHS	0.15	0.12
Turkey Point 3&4	Rock	Site-Specific	Plant-SSE	0.15	0.15
Vermont Yankee	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.25	0.14
Vogtle 1&2	Soil V	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.2
Waterford 3	Soil (SS)	Focused-Scope EPRI-SMA	SSE-Soil	0.1	0.1
Watts Bar	Rock	Focused-Scope EPRI-SMA	NUREG-0098 Rock/Soil	0.3	0.18
Wolf Creek	Rock	Focused-Scope EPRI-SMA	Plant-SSE	0.2	0.12

B.2 Comparison of Hazard Results

As discussed in Section 3 of the report, to perform an evaluation of the implications of changes in seismic hazard it is necessary to have hazard estimates from previously accepted studies in addition to the USGS results described above. To facilitate this comparison, the seismic hazard results developed by EPRI-SOG (EPRI NP-6935) and LLNL (NUREG 1488; Bernrouter and others) were used. Both of these studies were accepted for use in the IPPEE evaluation and provide a baseline from which changes in seismic hazard estimates can be evaluated. The

EPRI-SOG study did not perform an evaluation for all sites. Figures B.6, B.7, B.8, and B.9 show hazard results for several sites.

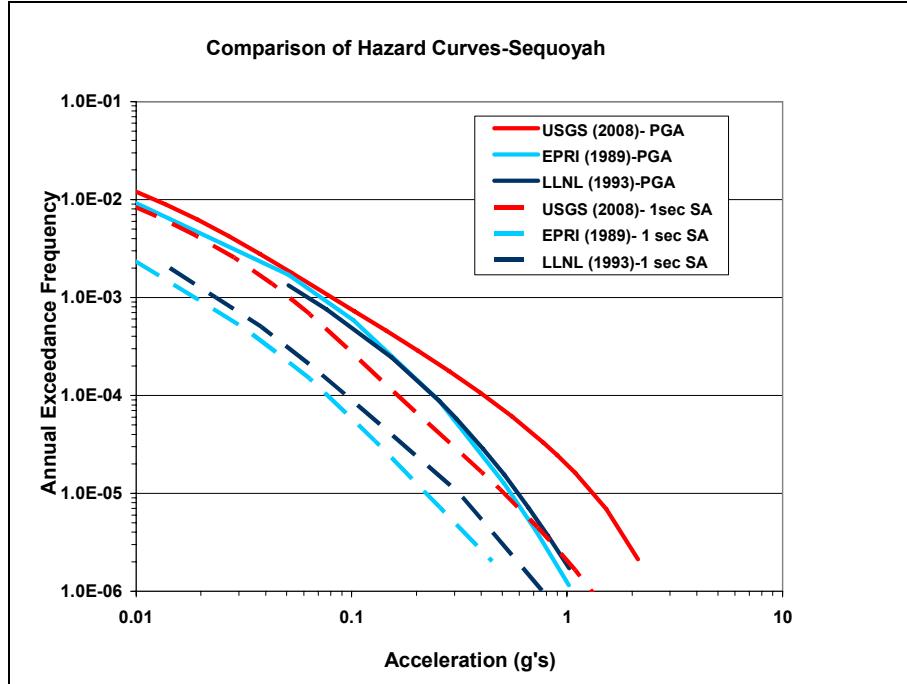


Figure B.6. Comparison of Hazard Results for the Sequoyah Site. The results from USGS (2008) are shown by red lines, EPRI (1989) by light blue lines, LLNL (1993) by dark blue lines, PGA by solid lines, and 1-sec SA by dashed lines.

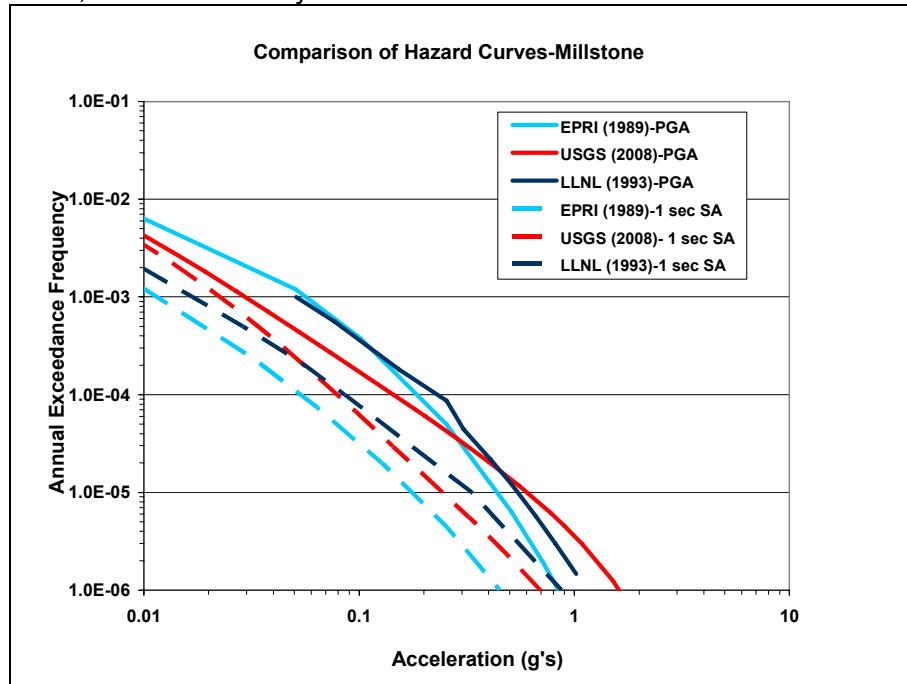


Figure B.7. Comparison of Hazard Results for the Millstone Site. The results from USGS (2008) are shown by red lines, EPRI (1989) by light blue lines, LLNL (1993) by dark blue lines, PGA by solid lines, and 1-sec SA by dashed lines.

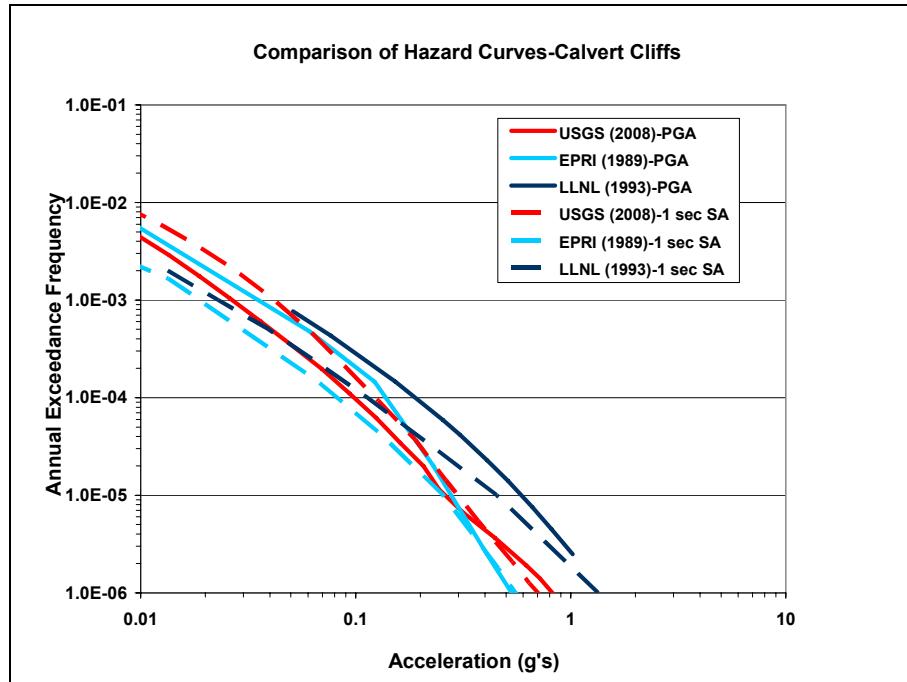


Figure B.8. Comparison of Hazard Results for the Calvert Cliffs Site. The results from USGS (2008) are shown by red lines, EPRI (1989) by light blue lines, LLNL (1993) by dark blue lines, PGA by solid lines, and 1-sec SA by dashed lines.

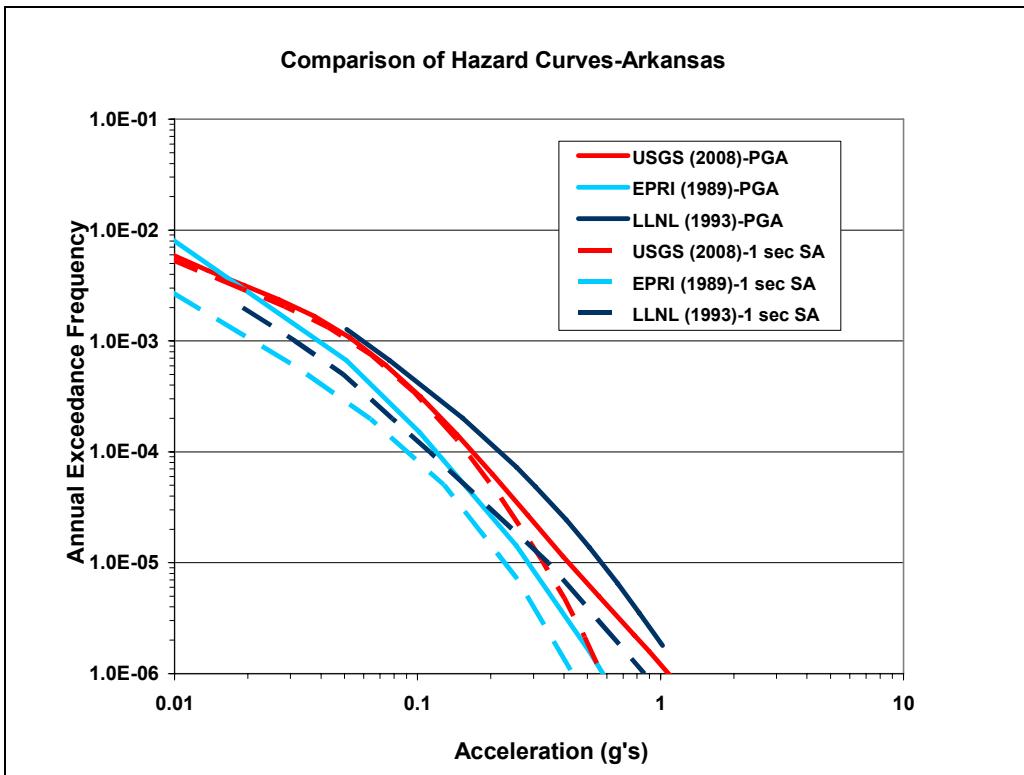


Figure B.9. Comparison of Hazard Results for the Arkansas Site. Results from USGS (2008) are shown by red lines, EPRI (1989) shown by light blue lines, and LLNL (1993) shown by dark blue lines, for PGA (solid lines) and 1-sec SA (dashed lines).

The general observation is that the more recent USGS hazard results are higher than the EPRI-SOG (EPRI-NP-6935, 1989) results at most sites. The difference is most pronounced for the 1-sec SA results. The difference becomes greatest for high amplitudes (i.e., low annual frequency of exceedance). The difference appears to be related primarily to two factors: (1) larger values assigned to M_{MAX} in the USGS model relative to the EPRI model and (2) the use of larger aleatory variability values in the modern ground motion attenuation models. The appropriate approach for developing M_{MAX} estimates in the CEUS is a topic of active discussion in the geosciences community. However, the aleatory variability estimates currently in use are considered superior to those used in the 1980-vintage studies. The USGS hazard estimates are generally higher than the 1993 LLNL study (especially at 1-sec SA), but at some locations the LLNL results are much higher than either the EPRI or USGS results.

B.3 Evaluation of Changes in Seismic Hazard Estimates

To develop additional insights that may help in the Safety and Risk Assessment Stage, additional comparisons of the changes in seismic hazard were made. Section 4 of the main body of the report shows the results of these comparisons. In addition, Figures B.10 and B.11

show a comparison of PGA and 5 Hz SA for an annual exceedance frequency (AEF) of 1E-5. This comparison shows trends in USGS (2008), EPRI (1989), and LLNL (1993) hazard results across the entire suite of CEUS plants. The general trend is consistent with time in that the relative ranking of plants is generally the same (for example plant #30 is high on all estimates and plant #50 is low on all indices). However, it is apparent that the EPRI (1989) results are generally lower than either the LLNL or USGS results. Figures B.10 and B.11 show results from recent early site permits (ESP) and combined licenses (COL) submittals as well. Direct comparison of the ESP/COL data is complicated by the use of the CAV filter for some of the ESP/COL sites and because the site conditions for some of the ESP/COL sites are different than those for the nearby existing NPP site.

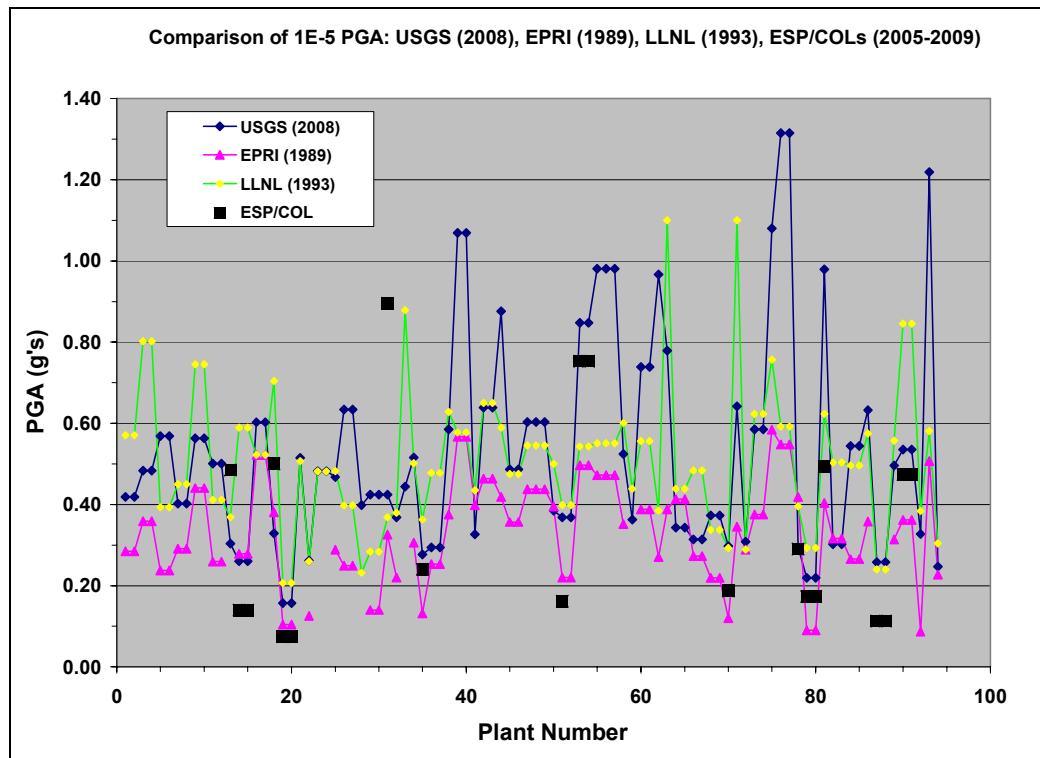


Figure B.10. Comparison of Peak Ground Acceleration (PGA) Hazard Results for CEUS Plant Sites at an AEF of 1E-5. The USGS (2008) results are shown by in dark blue, EPRI (1989) in magenta, and LLNL (1993) by green lines. Results from ESP and COL submittals indicated by black squares.

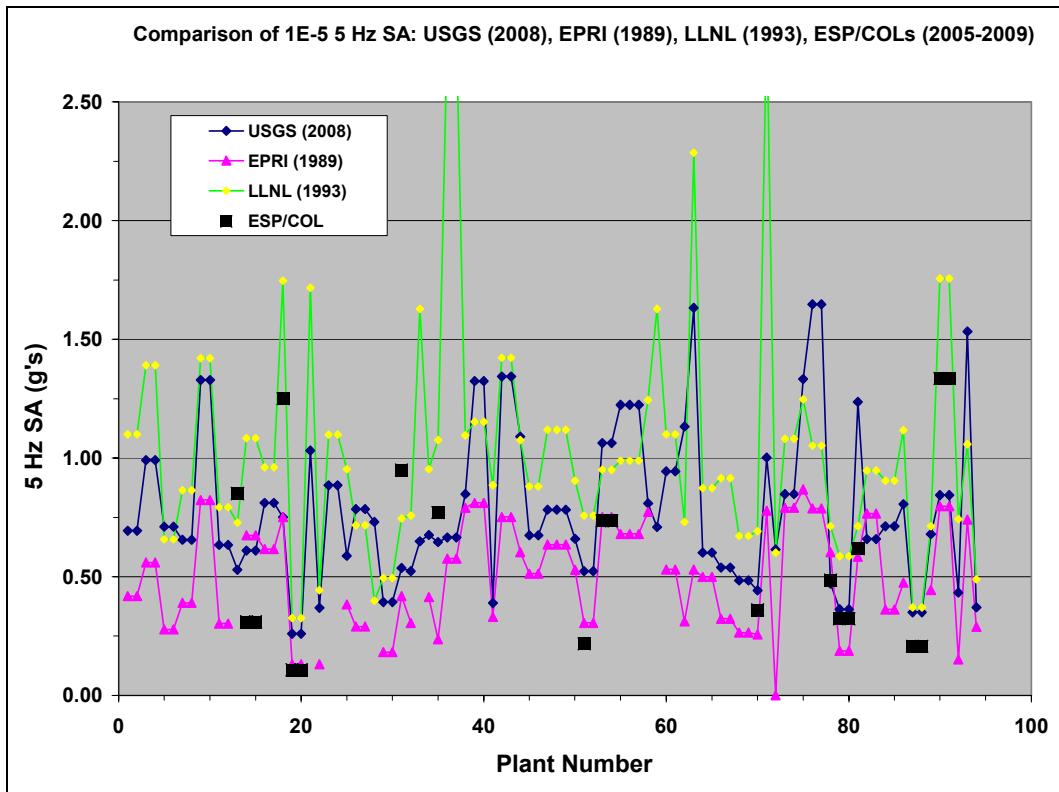


Figure B-11. Comparison of 5 Hz SA Hazard Results for CEUS Plant Sites at an AEF of 1E-5. The USGS (2008) results are shown by in dark blue, EPRI (1989) in magenta, and LLNL (1993) by green lines. Results from ESP and COL submittals are indicated by black squares.

As is discussed in Appendix A and shown by Kennedy (1997), an estimate of SCDF can be obtained directly from a basic set of plant-level fragility information (capacity expressed as either C_{50} or HCLPF and a measure of composite uncertainty, β_c) coupled with site-specific seismic hazard curves. In particular, because the seismic hazard curves are about linear over a relevant range of amplitudes in log-log space, the seismic hazard can be represented by two parameters: slope (represented by K_H) and intercept (represented by K_I). So, for a fixed set of assumptions regarding fragility at a particular site, the SCDF risk metric will change with changes in K_H and K_I . Figure B.12 compares the distribution of K_H vs. K_I for the 2008 USGS, 1989 EPRI, and 1993 LLNL PGA hazard results for rock sites in the CEUS. Although some overlap occurs, a clear distinction is noted between the three hazard results. Lower values of K_H and higher values of K_I indicate regions of increased SCDF (for fixed fragility assumptions). The USGS results generally indicate increased risk relative to previous estimates.

Figure B.13 is similar to Figure B.12 but compares the K_H vs. K_I results for 5 Hz SA. The conclusions are similar to those noted above for PGA. However, greater dispersion exists in the USGS results and more overlap between the USGS and LLNL results for the 5 Hz SA case.

The K_H and K_I values for these comparisons were derived from the USGS, EPRI, and LLNL hazard results over the 10^{-4} to 10^{-5} AEF range. The choice of amplitude range over which to perform the fit will influence the results. However, this amplitude range is consistent with a

range relevant for the development of GMRS and based on more detailed calculations is a range that has a significant impact on SCDF. The comparison is made for rock sites as the influence of site-specific amplification functions can lead to very large changes for soil sites relative to rock.

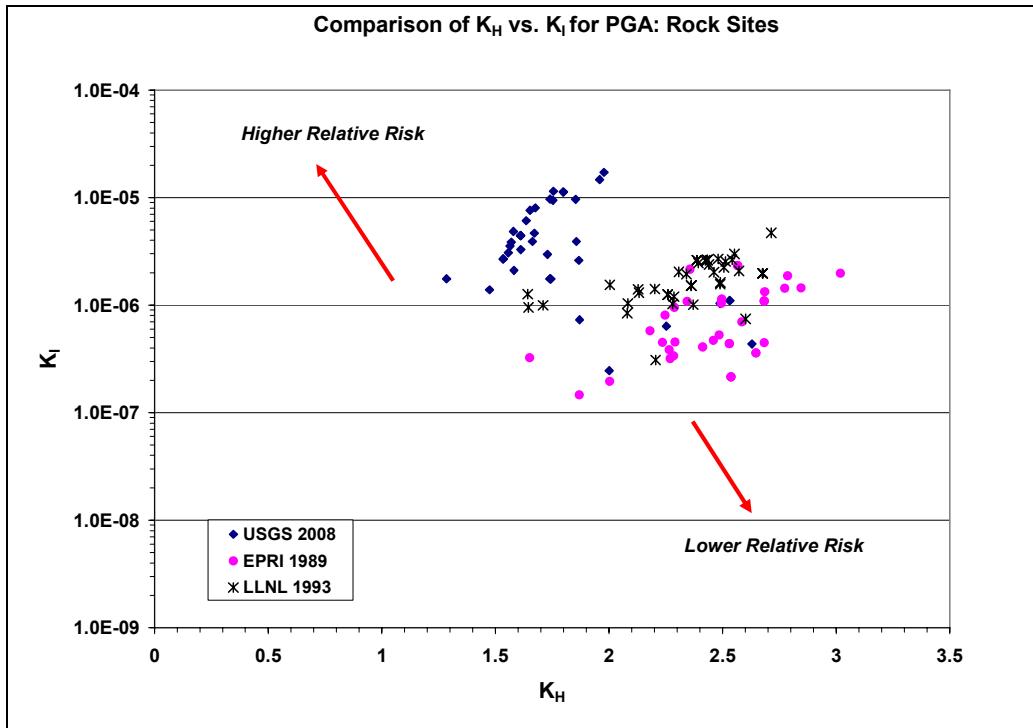


Figure B.12. Comparison of K_H vs. K_i Values for PGA at CEUS NPPs with Rock Site Conditions. The USGS (2008) results are shown by dark blue diamonds, EPRI (1989) with magenta circles, and LLNL (1993) by black stars. Regions of increasing and decreasing relative risk are indicated.

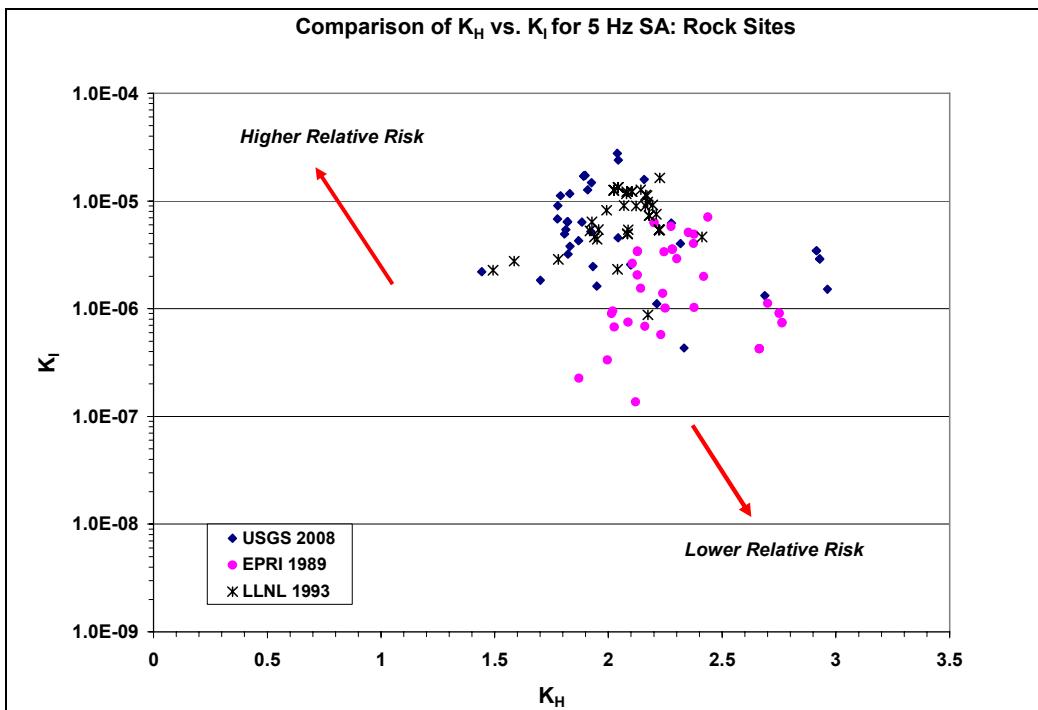


Figure B-13. Comparison of K_H vs. K_I Values for 5 Hz SA at CEUS NPPs with Rock Site Conditions. The USGS (2008) results are shown by dark blue diamonds, EPRI (1989) with magenta circles, and LLNL (1993) by black stars. Regions of increasing and decreasing relative risk are indicated.